MANAV RACHNA INTERNATIONAL UNIVERSITY

Short Synopsis
For

Ph. D. Program 2009-10

Assembly Line Balancing and Optimization through Mathematical Modeling

DEPARTMENT OF MECHANICAL ENGINEERING
FACULTY OF ENGINEERING & TECHNOLOGY

Submitted by:
Name: Saroj Kumar Gupta

Registration No.: 09019990191

Supervisor:

Name: Dr. V.K Mahna
Designation: Dean Academics
MRIU

Joint-Supervisor:

Name: Dr. Ran Vijay Singh
Designation: Professor and HOD,
Mechanical Engineering Deptt.

Abstract

An assembly line in a production process represents critical flow of a product wherein the constituent's parts are added to culminate in an intended finish product. This makes the manufacturing process much faster vis-à-vis handcrafting methods which are antiquated when it comes to optimizing a production process. Assembly line model are more efficacious both for mass production and labor oriented production. Real world assembly line balancing related to finite set of work elements and each element has a relationship of processing time and precedence. Line balancing is an attempt to equalize amount of work to each work station to achieve the desired efficiency by concentrating the factors like minimizing number of work stations, work load variations and cycle time minimization etc. The decision of optimization is very much dependent on the type of Assembly Line Balancing Model used. In the present study, multi model assembly line is optimized through application of Lean principles and statistically based work sampling survey's including actual time study through stop watch. The data so collected was put to regression analysis of mathematical modeling to ascertain a) Correctness of data, b) Optimization of data. On observation, there is a wide gap between settled targets of production on comparison with actual production targets. This gap is 46.3% which can be compensated by reducing throughput time. Also, the creation of buffer stock though may increase inventory. Yet the throughput will be smooth including timely delivery to the customer.

Keywords: Mass Production, Processing Time, Precedence, Line Balancing, Cycle time minimization, Lot size

CONTENTS

S. No.	Description	Page no.
1	Introduction 1.1 Parameters for Assembly Line 1.2 Need for balancing of Assembly Line	1-3
2	Literature Review	4-6
3	Problem Formulation 3.1 Objective of the study	7 8
4	Methodology	9-11
5	Proposed outcomes of the study	12
6	References	13-14

I. INTRODUCTION

"An assembly line is a manufacturing process in which parts are added to a product in a sequential manner using optimally planned logistics to create a finished product in the fastest possible way. It is a flow-oriented production system where the productive units performing the operations, referred to as stations, are aligned in a serial manner".

Assembly Lines, by and large are manual lines wherein the performance of each station is related to the performance of the man allocated to that station. Since, no two men are alike therefore; the performance also has to be different. Apart from performance, the allocation of tasks to the stations is not uniformly distributed may be because of certain constraints. These imbalances lead to loss in the line efficiency which needs to be looked into. Therefore, it is essential to measure the working efficiency of the existing line at each station so-that, the task allocation and the precedence can be reviewed systematically. The problem can be solved by reconfiguring the line by way of reallocation of tasks including merging of the tasks to create all together new stations which may be less than the existing stations.

Assembly lines are an integral part of any manufacturing process to complete a product. These lines are fundamentally flow lines in which the work moves from one station to another with addition of material at each station. Under ideal conditions, the elemental time at each station has to be same. This statement is quiet contrary in the real world situation since, most of assembly lines are manually operated giving rise to different timings at each station as per the capacity of the man allocated to the station. Line efficiency is associated with three major issues like (a) Relationship of output with number of stations and accordingly allocation of man power, (b) Cycle time at each station, and (c) Speed of performance.

In the classical production line only products with the same options are processed at once while products of different models, providing distinct options, are either processed on a different line or major equipment modifications are necessary. Assembly Line Balancing is the art of assigning work elements to workstations along an assembly line, in such a way that the assignment be optimal in some sense. The objectives of balancing and optimization of assembly lines is

twofold, either cost minimization or profit maximization. The various characteristics for purpose of balancing and optimization are as follows:

1. Number and variety of product.
2. Line control.
3. Variability of task times.
4. Line layout.
5. Parallelization of assembly work
6. Equipment and processing alternatives
7. Assignment restrictions
8. Worker productivity.

Any Assembly Line Balancing Problem (ALBP) consists of three basic elements for purpose of classification i.e. (a) Precedence graph characteristics that comprises all tasks and resources to be assigned, (b) Station and line characteristics, and (c) Objectives which evaluate solutions.

1.1 Parameters for Assembly Line

The parameters which are important for making decision of optimizing the line or balancing the assembly line as follows:

a) The type of model used,
b) Automation of assembly line for better productivity,
c) Precedence diagram,
d) Cycle Time at each station,
e) No. of workstation,
d) Lot size and others.

1.2 Need for balancing of Assembly Line

In real world, assembly line balancing relate to finite set of work elements, and each element having relationship of processing time and precedence. Line balancing is an attempt to equal amount work to each work station to achieve the desired efficiency by concentrating the factors like minimizing work stations, minimizing work load variations and cycle time minimization.

Therefore, assembly line balancing attracted the attention of researchers who tried to support practical configuration planning by suited optimization models. In spite of the great amount of extensions of basic assembly line balancing there remains a gap between requirements of real configuration problems and the status of research.

Assembly line balancing in automobile industry is of big interest because of complex nature of problem, deviating situation including objectives. The multi model assembly line (MALB) has many variants for purpose of consideration. Also, the manual assemble line lead to either blocking or starvations because of non uniforms cycle time at each station. In this case study, the problem of reconfiguration is not redesigning the line which may include retention of the workers, sweeping changes in layout design or reallocating space for storage. By reconfiguration over here, it is assumed that line efficiency is to be enhanced either by reducing the no of stations or by regrouping the cycle times which will maximize the utilization and reduce blocking-starvation problem as far as possible.

Over the last few years, a lot of work has been carried out for processing alternatives. Two different approaches have been proposed to incorporate processing alternatives into ALB. Therefore, there is a dire need of systematic evaluation to identify those decision concepts- combining a (theoretical) problem type considered, the optimization model derived and the (exact or heuristic) solution method applied- which may be best suited to solve real world assembly line problems.

2. Literature review

Chakravarty and Shtub (1985) research is based on mixed-model line balancing. They worked on the problem of combining line balancing with lot sizing in a multi-product environment. Recent developments in the area of multi-echelon production/inventory systems were applied, and algorithms were developed which determine the number of work stations required along the line, the tasks assigned to each station, and the cycle time. The algorithms were designed to minimize total production costs composed of labor costs, inventory carrying costs, and setup costs. This work suggests a design approach which integrates labor cost with in-process inventory cost and machine set-up-cost.

Ghosh and Gagnon (1989) present a literature review and analysis of the assembly line balancing and scheduling of assembly systems. Quantitative developments and qualitative issues were discussed at the strategic and tactical levels. They classified the assembly line balancing problems in four classes: single model deterministic, single model stochastic, multi/mixed model deterministic and multi/mixed model stochastic. The literature review of simple and general cases of each of these problems was discussed. The methodologies as well as the objective criteria were also presented. Moreover, eight important factors that affect the design and balancing of the assembly systems were stated. These were output focus, line type, process and equipment considerations, facility considerations, workstation considerations, task related considerations, worker related and schedule related considerations. The factors organized in hierarchical and factor/design taxonomy are defined to access the progress in assembly line balancing.

Womack et al. (1990) explained the several features of lean. According to them, Lean is a systematical approach to identify and eliminate waste through continuous improvement following the product at the pull of customer in pursuit of perfection. Also, the lean principles require the rooting out everything that is non-value-added that means elimination of wastages from the entire process.

Farnandes (1992) suggested that the two major problems were encountered in planning and operating a mixed-model production line: line balancing and sequencing of products into the line. The ideal sequence of products into the line is such that the idle time resulting from an

imperfect balance will not increase. Up to now, it seems that heuristic methods to solve the line balancing and sequencing for mixed-model lines are still the best option. Even small problems result in such a great number of constraints that it was not practical (sometimes even impossible) to solve them through the use of optimum algorithms. The several factors contribute to render the solutions obtained by optimum algorithms were less than the actual optimum. Such factors include the variability in work element times. Heuristic methods for the line balancing of single model assembly lines can be extended to mixed-model lines through a slight adaptation in his work. This results in shorter lines and smaller throughput times. Also, the concurrent work (two adjacent operators working on the same unit) also tends to reduce throughput time and for open stations the best launching interval appears to be variable launching rate, while for closed stations fixed launching rate is best.

Becker and Schooll (2003) purposed that the Assembly Line Balancing Problem consist the finding of a feasible **line balance**, i.e., an assignment of each task to a station such that the precedence constraints and further restrictions are fulfilled. A usual surrogate objective consists in maximizing the line utilization which is measured by the **line efficiency** as the productive fraction of the line's total operating time and directly depends on the cycle time c and the number of stations. The survey reveals that assembly line balancing research which traditionally was focused upon simple problems (SALBP) has recently evolved towards formulating and solving generalized problems (GALBP) with different additional characteristics such as cost functions, equipment selection, paralleling, U-shaped line layout and mixed-model production.

Merengo et al. (1999), states if only one product was assembled, all work pieces are identical and a single-model line is present. If several products (models) are manufactured on the same line, the ALBP is connected to a sequencing problem which has to decide on the sequence of assembling the model units. The sequence is important with respect to the efficiency of a line, because the task times may differ considerably between the products. Depending on the type of intermixing the units two variants arise: A mixed-model line produces the units of different models in an arbitrarily intermixed sequence, whereas a multi-model line produces a sequence of batches (each containing units of only one model or a group of similar models) with intermediate setup operations. Therefore, balancing and sequencing are connected to a lot sizing problem.

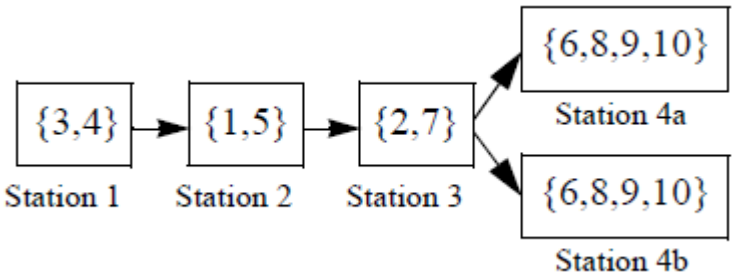

Fig. 1 Parallel stations

Dolgui et al. (2003) forced on Paced production lines which represent hard automation and for the mass production of a single type of parts. The parts machined were characterized by a great number of operations and surfaces to be machined, by several types of machining and by a relative big cost. These production lines were usually designed as synchronous (indexing) ones (i.e. without buffers). Their experiments showed that the algorithm allows finding an exact solution in one hour for problems when the number of operations is not greater than 100. They further suggested that for solving large-scale problems, the algorithm should be combined with heuristics techniques. Two kinds of heuristics are possible. The second kind is to decrease the digraph size due to simplifying the rules for ignoring non promising variants. The second kind is to use partitioning the set of operations in subsets and applying the optimization procedure for each subset repetitively.

Boysen et al. (2007) revealed the high capital requirements when installing or redesigning a line, its configuration planning is of great relevance for practitioners. Accordingly, this attracted attention of many researchers, who tried to support real-world configuration planning by suited optimization models (assembly line balancing problems). In spite of the enormous academic effort in assembly line balancing, there remains a considerable gap between requirements of real configuration problems and the status of research. To ease communication between researchers and practitioners, a classification scheme of assembly line balancing is provided. This is a valuable step in identifying remaining research challenges which might contribute to closing the gap. The structure provided in this paper, might also be employed to develop new instance generators and solution procedures which cover all or a certain systematic subset of important problem characteristics.

3. PROBLEM FORMULATION

The study about Balancing of the Assembly Line till date has been carried out for the purpose of research in real world scenario. Boysen et al. (2007) suggest that despite enormous academic effort in assembly line balancing, there remains considerable gap requirements of real world and status of research. Becker and Scholl (2006) reviewed 312 research papers and strangely 15 papers were identified which exclusively deals with balancing of real world assembly system. The research on Assembly Line Balancing is going on since 1955 and after a lap of 55 years; the gap between industrial reality and academic theory still exists and has been confirmed by Andres et al. (2007). The major problem with most approaches reported by Becker and Scholl (2004) is that they generalize assembly line balancing optimization problem (ALBOP) in just one or two directions. The real world line balancing as faced in particular by automotive industry requires tackling of that generalization. he statements of Falkenawer (2010) and by Scholl (2004), very much favor to study ALB in automotive industry with Un-paced conditions. Further the assembly lines could either be of single model of the same product.

The shock absorbers assembly line in M/s Escorts Ltd. is studied for the purpose of research. As discussed by many researchers that the majority of assembly lines rely on manual labor. Especially, under Indian conditions, the balancing of assembly lines is a complex process because the lines rely on manual labor and the variation in human performance. This research work deals with fixed worker (FW) type of assembly line and not walking worker (WW). Under the circumstances the work completed at precedent stations is passed on to successive stations. During research work, it was observed that following are the key factors responsible for unevenness in Assembly Line Balancing Problem (ALBP).

- Low utilization of the workforce at 49%.
- Waiting for material 29%.
- Setup change 16%
- Wrong lot size as the present lot size of 500 numbers is quit big as compared to derive data regarding lot size as 270 numbers
- Lot of inventories because of unplanned scheduling and also no attempt to control the inventories whether on regular basis even at periodic basis.

The above factors were taken in to consideration for study, modeling and optimization of shocker absorbers assembly line of Escorts Ltd.

3.1 Objective of the work

The study about Balanced Assembly Line till date has been carried out to define problem for purpose of research. Boysen et al. (2007) suggest that despite enormous academic effort in assembly line balancing, there remains considerable gap requirements of real world and status of research. The objective of the present research work is as follows:

1. To study about Assembly Line Balancing (ALB).
2. To review the work carried out by various researchers on ALB>
3. To identify the ALB problem in Bi-wheeler and Four-wheeler Shockers of M/s Escorts Ltd., Faridabad.
4. To formulate the identified problem of shock absorbers assembly line of M/s Escorts Ltd.
5. To develop mathematical model for optimization of collected data of Shock Absorber Assembly Line at M/s Escorts Ltd.
6. To analyze and compare the results.
7. To suggest the model developed and optimized for implementation.

4. Methodology

A particular process or system needs a thorough investigation to discover the inbuilt elements in the systems. Most of the problems in science and engineering require observation of the system at work and experimentation to explain information about why and how it works. Well-designed experiments can often leads to model of systematic performance which are nothing but empirical model.

The optimization of Assembly Line is quite complex and number of researches have been carried in many ways like Mathematical Modeling, Heuristic Modeling, Tabu Search and Simulated Annealing (SA), Ant Colony Method, Multi Ant Colony Method and others including Genetic Algorithm.

The data of planned production, actual production, variance category-wise of 203 components was collected on monthly basis. First and foremost step is to determine work elements which are known as TASKS. Subsequently it is determination of sequence in which task is to be performed. This is known as TASK PRECEDENCE. Then is the determination of time in which task is performed and may be called as TASK TIMES. Finally it comes to determination of time in which product shall come out. This is generally called CYCLE TIME. This leads to process of LINE BALANCING in terms of

a) Grouping elements to have synchronically station time
b) Minimizing work stations by grouping tasks

The output from line is solely dependent on utilization of men & Equipment. This means fitment of tasks as per their task times. Mathematical model will be applied to maximize

a) output
b) utilization
c) efficiency

In present work entire data is based on sampling which is random in nature. The statistics can be defined as any function of the observation in a sample that doesn't contain unknown parameters. As discussed in literature Lean is a scientific tool to identify any waste which doesn't add value to the process/service. These wastes are generally of seven types and overproduction (waste) has

been picked up for the purpose of study. VED analysis (Vital, Essential, and Desirable) is a tool applied for periodic check of inventory levels and to keep the levels within desired limits as there should be no shortage or blocking. Further regression analysis is required to get the final results and the Hypothetical testing is required to access the correctness of the data collected and analyzed. The research plan is shown in figure 2, 3 and 4 respectively.

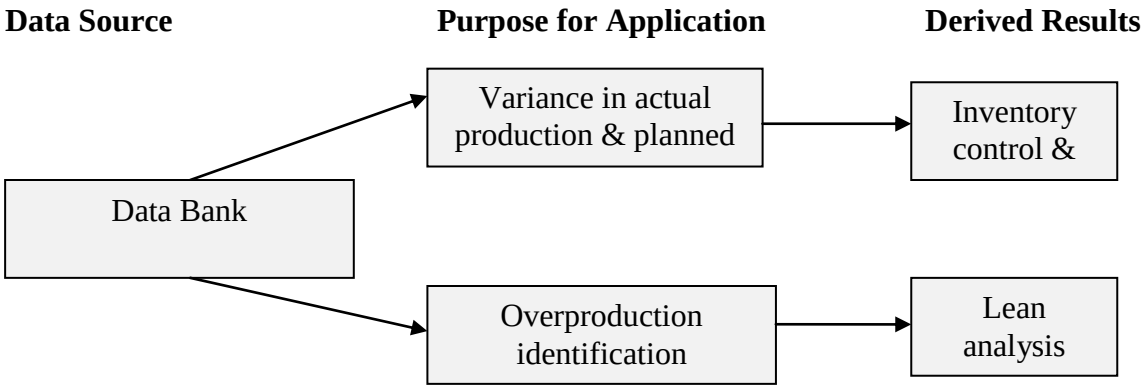

Fig. 2 Flow chart for segregation of data

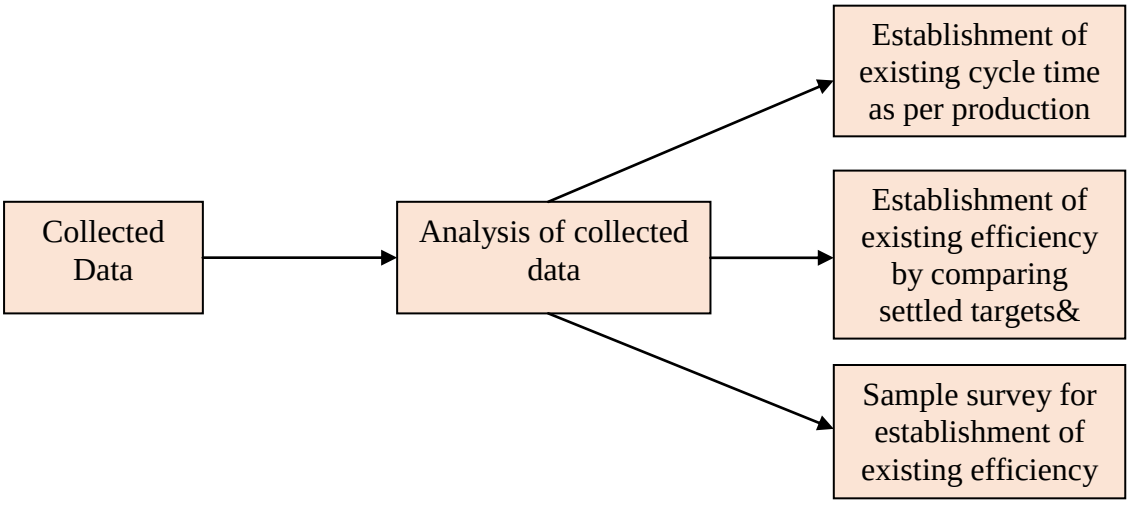
Establishment of existing cycle time as per production
Collected Data
Analysis of collected data
Establishment of existing efficiency by comparing settled targets&
Sample survey for establishment of existing efficiency

Fig. 3 Flow chart for analysis of data

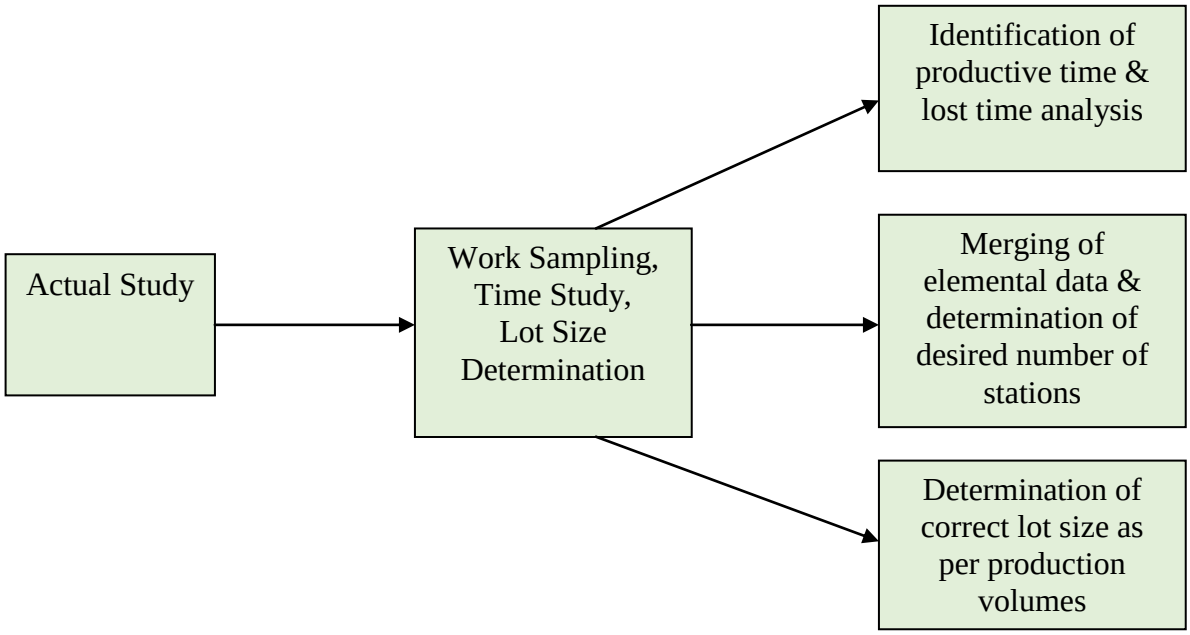
Actual Study
Work Sampling, Time Study, Lot Size Determination
Identification of productive time & lost time analysis
Merging of elemental data & determination of desired number of stations
Determination of correct lot size as per production volumes

Fig. 4 Work sampling flow diagram

5. Proposed outcomes of the study

Data of 203 components of bi-wheeler/four-wheeler shock absorber of ALB was collected considering different parameters to develop and optimize the model and results were also analyzed. Following are the outcomes and conclusion of the research work

1. Existing nine workstations are reduced to seven stations to get the same results
2. Cycle time is reduced from 32 Sec to 11.3 Sec
3. Efficiency is improved from 26.3% to 98%
4. Reproductive time for men and machine is enhanced from 48% to 82%
5. The VED analysis help in identifying 7 items out of 203 items for critical control,11 items out of 203 items for slightly less strict control, and 17 items out of 203 items for normal control.
6. The lot size has been re-fixed at 270 numbers against 500 numbers in present scenario.
7. While reworking out the elemental time for purpose of revise number of stations was kept same.
8. Zig-Zag movement of material for first three stations has been smoothen out by regrouping the elements.

It is concluded from the above outcomes that lot size will get reduced to its logical value, task time revised, cycle time reduced, no. of workstations reduced, no. of manpower reduced, smooth availability of material, high utilization and reduced no. of setup's.

REFERENCES

1. Agpak, K. and Gokcen, H. (2005). "Assembly line balancing: Two resource constrained cases", *International Journal of Production Economics*, Vol. 96, pp. 129–140.
2. Ahmed, F. (2008). "Comparative Study between Mixed Model assembly Line and Flexible Assembly Line based on cost minimization approach", Thesis Submitted in UniversitiSains Malaysia.
3. Bartholdi, J., Bunimovich, L.A. and Eisenstein, D.D. (1999). "Dynamics of Two and Three-Worker "Bucket Brigade" Production Lines, *Operations Research*, Vol. 47, Iss. 3, pp. 488-491.
4. Bartholdi, J.J., & Eisenstein, D.D. (1996). "A production line that balances itself", *Operations Research*, Vol. 44, Iss. 1, pp. 21-34.
5. Becker, C. and Scholl, A. (2003). "A survey on problems and methods in generalized assembly line balancing", *European Journal of Operational Research* ISSN: 1611-1311.
6. Boysen, N., Fliednera, M. and Scholl, A. (2008). "Assembly line balancing: Which model to use when?", *International Journal of Production Economics*, Vol. 111, pp. 509–528.
7. Boysen, N., Fliedner, M. and Scholl, A. (2007). "A classification of assembly line balancing problems", *European Journal of Operational Research*, Vol. 183, pp.674-693.
8. Cao, Z. and Ma, S. (2008). "Balancing and Sequencing Optimization of the Mixed Model Assembly Lines", *International Symposium on Computer Science and Computational Technology*, Vol. 1, Dec. 20-22, 2008, pp. 732-736.
9. Chiang, W.C. and Urban, T.L. (2006). "The stochastic U-line balancing problem: A heuristic procedure", *European Journal of Operational Research*, Vol. 175, No. 3, pp.1767-1781.
10. Erel, E. and Hadigokcen, H. (1999). "Shortest-route formulation of mixed-model assembly line balancing problem", *European Journal of Operational Research*, Vol. 116, pp. 194-204.
11. Eklund, J.A.E. (1995). "Relationships between ergonomics and quality in assembly work", *Applied Ergonomics,* Vol. 26, Iss. 1, pp. 15-20.
12. Eklund, J.A.E. (1997). "Ergonomics, quality and continuous improvement-conceptual and empirical relationships in an industrial context", *Ergonomics*, Vol. 40 Iss. 10, pp. 982-1001.
13. Emanuel Falkenauer (200x). "Line Balancing in the Real World", *International Conference on Product Lifecycle Management,* Inderscience Enterprises Ltd.
14. Guo, Z.X., Wong, W.K., Leung, S.Y.S., Fan, J.T. and Chan, F.S. (2008). "A Genetic-Algorithm-Based Optimization Model for Solving the Flexible Assembly Line Balancing Problem with Work Sharing and Workstation Revisiting", Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE,**Vol.** 38, Iss. 2, pp. 218 – 228.
15. Hirotani, D., Myreshka, Morikawa, K. and Takahashi, K. (2006). "Analysis and design of self-balancing production line", *Journal of Computers & Industrial Engineering,* Vol. 50, Issue 4, pp. 488–502.
16. Hirotani, D., Morikawa, K. and Takahashi, K. (2010). "New worker policy for self-balancing production line with stations", *The 11th Asia Pacific Industrial Engineering and Management Systems Conference (APIEM),* Melaka, 7 – 10 December 2010.

17. Lambert, A.J.D. (2006). "Generation of assembly graphs by systematic analysis of assembly structures", *Journal of Operational Research*, Vol. 68, pp. 932–951.
18. Paranitharan, P.M., Begam, M.S., Abuthakeer, S.S. and Subha, V.M. (2011), "Redesinging an Automotive Assembly Line through Lean Strategy", International Journal of Lean Thinking, Vol. 2, Iss. 2, pp. 1-14.
19. Shaaban, S. and McNamara, T. (2009). "Transient Behavior of Unbalanced Lines"' *Proceedings of the World Congress on Engineering and Computer Science (WCECS 2009),*Vol II, San Francisco, USA, October 20-22, 2009.
20. Zhang, W., Gen, M. and Lin, L. (2008) "A Multi objective Genetic Algorithm for Assembly Line Balancing Problem with Worker Allocation", *International Conference on Systems, Man and Cybernetics*, IEEE, Oct. 12-15, 2008, pp. 3026-3033.